THE EFFECT OF ADAPTATION TO HIGH ALTITUDE ON MAN'S TOLERANCE OF ACUTE HYPOXIA, HIGH TEMPERATURE AND VESTIBULAR IRRITATIONS

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ABSTRACT: In three different groups (mountain climbers, physically trained men and scientific staff) the tolerance of acute hypoxic hypoxia, high temperature and vestibular irritations was investigated before and after residence in mountains. The increase in tolerance to acute hypoxia in the majority of persons living for the first time under high-altitude conditions was established. The tolerance to elevated temperature after residence in the mountains was lowered insignificantly and the tolerance to vestibular irritations was somewhat increased.

An increase in tolerance of the effect of acute hypoxia in /57
healthy subjects after residence in mountains at altitudes on the order of 2000 - 7000 m has been noted by Sirotinin, Vladimirov, Malkin, Vasil'yev, Hartmann, Luft et al [2,4,5,7,8].

There exist data that daily training for a period of a month in a pressure chamber at an altitude of 6000 m of healthy subjects will lead to an increase not only of their altitude tolerance but also to the effect of high and low temperature [6].

The purpose of this research was to study the effect of adaptation to high-altitude conditions on the tolerance of healthy subjects to the effect of acute hypoxic hypoxia, high temperature of the environment and vestibular irritations.

The investigation was carried out with different groups of /58
healthy subjects: 11 highly qualified athlete-mountain climbers (1st group), 10 young, physically well-developed men (2nd group), who had previously not resided in mountains, and with 5 scientists (3rd group) who were participating in carrying out this research.

Adaptation to high altitude in five of the healthy subjects in 1964 was carried out gradually: 12 days at an altitude of 2000 m (Terskol); 12 days at an altitude of 3800 - 4200 m (Ledovaya) Baza and Priyut Odinnadtsati) and 5 days again at an altitude of 2000 m. In 1965 the time of residence at an altitude of 3800 and 4200 m was extended to 20 days for this same group of subjects.

The mountain climbers remained for a period of 6 days at an altitude of 2000 m (Terskol), after which they descended.

The group of scientists remained basically for a period of 25 - 28 days at an altitude of 2000 m (Terskol), but periodically (in connection with the research to be conducted) descended to Ledovaya Baza and for a brief time to Priyut Odinnadtsati. At Ledovaya Baza each scientist spent from 4 to 6 nights.

Before and after remaining in the mountains, a determination of the tolerance was made for each of the participants of the expedition. For this purpose, under pressure-chamber conditions, the subjects without oxygen in "stages" ascended to an altitude until distinct signs of a deep hypoxic state appeared, such as roughness in writing, losses in the ability to solve elementary arithmetical problems, cramps in the hand (writing cramps), different depth of disruption of consciousness.

In the first experiments with five subjects prior to and following ascent into the mountains, the altitude of the "ascent" in the pressure chamber did not exceed 7000 m and only the time of residence at this "altitude" was taken into account. In all the other studies the "ascent" was carried out according to the following schedule. To an altitude of 5000 m at a rate of 25 m per second and with a landing at each kilometer on the order of 15 - 20 sec; beginning from an altitude of 5000 m the landing at each subsequent altitude was five minutes.

In all of the subjects EEG's were taken on a multichannel ink-recording apparatus in the frontooccipital lead of an EKG in 3 standard leads and of respiration movement of the chest and periodically the blood pressure was taken. Simultaneously on an oximeter of "Krasnogvardeyets" type the saturation of the arterial blood with oxygen was recorded. Throughout the entire experiment a continuous observation was made on the behavior and overall condition of the subject.

To judge as to the ability to function and of intellectual activity the subjects, while remaining at high altitude, solved arithmetical problems (multiplication of two-digit numbers) and state of being was periodically recorded.

To study tolerance of the effect of high environmental temperature, 24 heat experiments were carried out in a thermal pressure chamber under conditions of normal barometric pressure at an environmental temperature of +70° C (the temperature of the chamber walls +90, +92° C) and a relative humidity of 40 - 65%. /59

The subject was placed in a chair in the chamber where there was no ventilation.

During the experiments the subject was continuously observed by a physician. Every 10 minutes successive physiological parameters were registered: EKG in the II lead; respiratory movement

of the chest; body temperature. At the end of the experiment water losses were determined.

Furthermore, the overall condition of the subjects were evaluated from their state of being and heat perception.

The EKG and the breathing were registered on an "Al'var" electroencephalograph. The body temperature was measured by an alcohol thermometer under the tongue. Water losses were determined by weighing the subjects before and after the experiment on medical scales.

In 10 of the subjects, before and after remaining at high altitudes, the functional condition of the vestibular analyzer was studies by continuous cumulation of coriolis accelerations). Using this method the subjects were rotated at a rate of 180° per second (1 turn in 2 seconds) in a special chair with the head and body in a vertical position and with eyes open. After 10 seconds following beginning of the rotation the subject in accordance with instructions inclined his head toward the right shoulder - this was the original position. From this position the subject turned his head toward the left shoulder every 5 - 6 seconds uniformly for 2 seconds then for the same period of time turned toward the right. The inclination of the head toward the shoulder was no less than 30° from the vertical on each side. The subject during the experiment reported on his state of being: on the appearance of the illusion of rocking and other sensations. With the occurrence of sickness, the time of its onset was registered which also determined the duration of the test.

From the discussion of experimental data we assume it to be feasible from the beginning to cite the results of the high-altitude investigations.

After remaining at high altitude, a distinct increase in the altitude tolerance was observed in five of the subjects who participated in the first expedition.

Four of the subjects, after remaining at high altitude, were able to stay at an altitude of 7000 m without oxygen for a period of 20 - 30 minutes, retaining fully a satisfactory overall condition and a sufficiently high level of ability to function. Prior to the high-altitude trip these subjects could remain at this altitude only for 1 to 8 minutes.

In later investigations we were able to change somewhat the method of determining altitude tolerances in connection with which /60 we attempted to compare the data from experiments carried out with different groups of subjects.

As our previously conducted research showed (see this collection, Russian page 147, English page 164*. Mountain climbers have

* Translator's note: not translated.

a high background altitude tolerance and as a rule during a relatively long time feel well at an altitude of 7000 m. Therefore in working with this group of subjects, it was necessary to make ascents to high altitudes.

TABLE 1. CHANGES IN THE ALTITUDES TOLERANCE PRIOR TO AND AFTER RESIDENCE AT HIGH ALTITUDES.

Subject	Prior to Mountains		After Mountains for 4-6 days		After Mountains for 28-31 days		Tolerance
	Altitude, m	time min. & sec.	Altitude, m	time min. & sec.	Altitude, m	time min. & sec.	
			Group 2				
A-v	9	2,00	8	5,00	8	5,00	Lowered
V-vo	8	3,10	9	1,00	8	5,00	Increased
K-as	7	5,00	8	4,30	8	3,40	"
Sh-k	8	1,30	9	1,10			"
Ku-s	9	0,50	9	2,20	9	1,40	"
			Group 1				
Ts-n	8	4,00	8	4,00			Unchanged
K-v	9	1,50	8	5,00			Lowered
B-n	9	1,10	9	3,20			Increased
K-yev	9	1,50	9	2,10			Unchanged
T-m	8	2,00	9	2,45			Increased
S-t	9	2,40	9	2,20			Unchanged
B-ov	9	0,40	9	2,00			Increased
N-v	8	1,30	8	5,00			"
G-r	8	5,00	9	1,40			"
B-d	9	0.40	9	2,10			"
M-r	9	1,10	9	1,10			Unchanged
U-a	8	1,20	8	4,30			Increased
R-a	7	1,10	8	2,30			"
L-a	7	1,30	8	2,00			"
M-ko	6	5,00	7	1,50			"
M-ns	5	4,30	5	5,00			Unchanged

Table 1 gives data on the altitude tolerance for 3 different groups of subjects prior to and after residence under high-altitude conditions.

For the young subjects who went into the mountains for the first time and who felt well at high altitudes and completed a successful ascent to the eastern peak of Elbrus, their time spent in the mountains led a pronounced (in 3 out of 5) increase in altitude tolerance. For one of the subjects who suffered from altitude sickness, the tolerance was somewhat lowered and for one who had a high background tolerance it was increased very little. /61

The change in altitude tolerance in mountain climbers was very insignificant. For four it varied practically none at all (improvement of less than 30 seconds), for one it was lowered and for six it was increased. However in 2 of the 6, the increase was caused by the fact that the background tolerance in them was lowered due to fatigue.

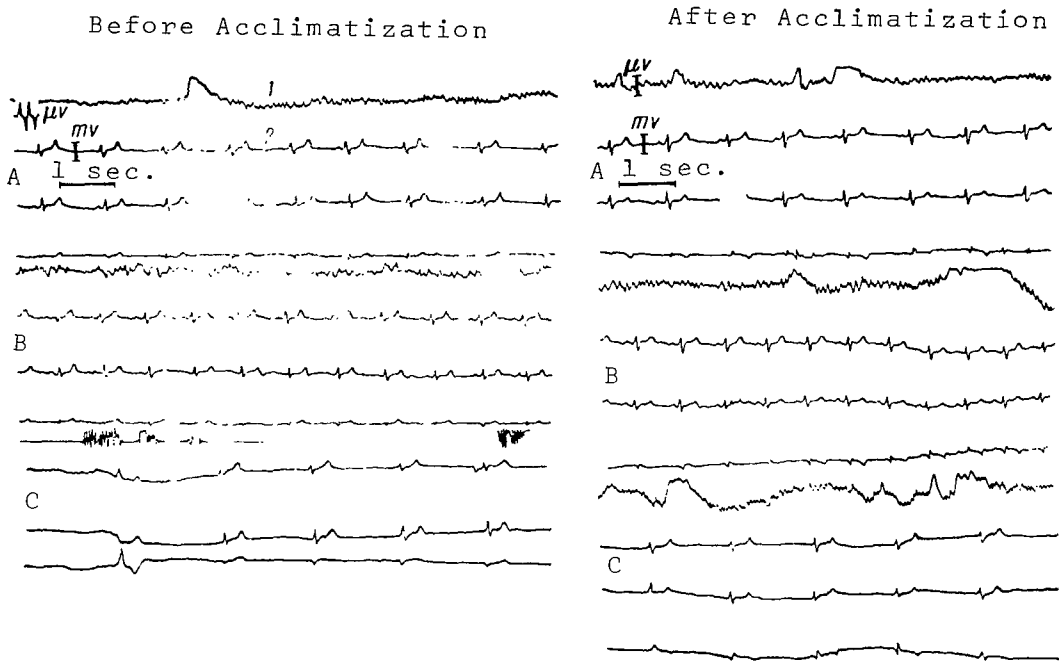
Any substantial increase in the tolerance of this group was in fact only in three subjects, two of which entered the mountains after a relatively prolonged interval. This apparently produced in these persons a lower background tolerance.

We attempted to find the dependence between the adaptation process in mountains and the high tolerance of the mountain climbers. For two of the mountain climbers (Ts-n and K-v) who had the greatest load and who had lived at altitudes on the order of 4000 - 4800 m for a longer time than the others, no increase was noted in their altitude tolerance; for one it was lowered, in the other it remained without substantial changes.

To explain these results of excessive physical load is premature, since for the mountain climbers, including Ts-n and K-v after expeditions to Tyan'-Shan (Khan-Tengri Province) with a large load (complex ascent with relatively prolonged residence at altitudes of 6000 - 7000 m) a slight increase was noted in their altitude tolerance.

For three of the scientists out of five after remaining at high altitudes, a distinct increase was found in their altitude tolerance, for one it was increased insignificantly and for another, who had low tolerance it remained without change. This last case (M-is) deserves special attention since even before the trip into the mountains, in the pressure chamber at an altitude of 5000 m after 4 minutes, 30 seconds, he lost consciousness with unexpectedly developed bradycardia, that was accompanied by convulsions. At high altitudes M-is functioned at altitudes of 3800 - 4200 m and felt fully satisfactorily, however after reaching an altitude of 5000 m in the 5th minute again his cardiac contractions slowed down, and the precollaptoidal condition occurred again (see the figure).

First of all we are interested in the causes that, after adaptation at high altitudes, lead sometimes to a sharp increase in altitude tolerance. Analysis of the data of registration of the physiological parameteters showed that in those persons there was noted at high altitude a sharp increase in breathing, as a result of which during the ascent to high altitude after remaining in the mountains the saturation of arterial blood with oxygen was considerably higher than in the control ascent.



EKG and EEG of Subject M-s during Ascent to an Altitude of 5000 m. 1. EEG left frontal-occipital lead; 2. first; 3. second; 4. third standard EKG lead. A. Before ascent; B. 5000 m, 1 min; C. 5000 m, 4 min. 30 sec. /62

This latter probably determined the improvements from the side/63 of the higher nerve activity and the bioelectric activity of the brain. After returning from the mountains they retained their ability to function with relatively little change in the EEG for a more prolonged time than before residence in the mountains.

It is worth noting that the saturation of arterial blood with oxygen at the moment that the high-altitude test ceased in persons who have shown an increase in tolerance was the same as in the control study or, in individual cases, even somewhat higher. This indicates that residence in mountains (adaptation to chronic hypox-

ia) gives no possibility to an organism to retain a sufficiently high level of ability to function under conditions of lower oxygen supply, but it is accompanied by a more effective and normal activity of the functional systems, which determine the transport of oxygen to the tissue structure which are more sensitive to hypoxia.

The unexpected improvements in altitude resistance in the various groups of subjects probably to a certain degree are due to differences in the duration of the process of acclimatization itself.

It is of interest to note the fact that altitude tolerance, just as tolerance to the effect of transverse G-loads, after high-altitude adaptation is partially retained for a period of a month and even longer time. The results of the heat experiments were unexpected for us. We assumed that residence in high altitudes would lead to an increase in tolerance of the subjects to high temperature. Moreover, in the experiments on animals carried out in conjunction with F.V. Babchinskiy, slight increase was noted in the survival of mice adapted at high altitudes at a temperature of +60° C. A similar effect was described by F.T. Agarkov [1] earlier.

The data which we found show that after 10 - 14 days following return from high altitudes in the majority of subjects a slight decrease is observed in their tolerance to high temperature. Here it is quite important that for almost all of the subjects following residence at high altitudes the increase in body temperature - the basic sign characterizing the reaction of an organism to overheating - occurs more rapidly than in the control experiments.

After return from high altitudes the overall condition of the subjects at the end of their stay in a heat chamber was considerably worse than in the control experiments. This is explained by the fact that in two of the subjects after adaptation at high altitudes at the end of the experiment a precollaptoidal condition set in, whereas all the control experiments ceased on request of the subjects due to the appearnace in them of unpleasant heat sensations. Thus, the impression was created that, in spite of the ability of the subjects after adaptation to high altitude to withstand more pronounced increases in body temperature, their tolerance was nevertheless found to be somewhat lowered.

The results of the investigation on tolerance of subjects to vestibular irritations are shown in Table 2. As is obvious from these data, prior to acclimatization in five subjects the time of endurance of cumulation of Coriolos accelerations was within a range of 2.5 to 6 minutes, and they belonged to the group of vestibular - tolerant subjects, the other five subjects - to vestibular tolerance since the tolerance time varied from 18 - 100 seconds. /64

Under the influence of high altitude acclimatization in the majority of subjects (in 7 out of 10) a prolongation was observed

TABLE 2. DETERMINATION OF VESTIBULAR TOLERANCE BASED ON THE METHOD OF ACCUMULATION OF CUMULATION OF CORIOLIS ACCERLERATIONS.

Subject	Tolerance time, min., sec.		Difference	Subject	Tolerance time, min., sec.		Difference
	Before Acclimatization	After Acclimatization			Before Acclimatization	After Acclimatization	
K-v	3.45	9.05	+5.20	U-n	0.18	0.45	+0.27
V-ko	4.30	12.00	+7.30	S-t	1.10	1.35	+0.25
Ku-s	2.30	3.30	+1.00	G-r	1.40	2.20	+0.40
K-as	6.00	6.00	0.00	N-v	1.05	1.30	+0.25
A-v	4.00	1.00	-3.00	K-ov	1.25	1.00	-0.25

of the tolerance time to Coriolis accelerations. This was noted especially in the 3 vestibular - tolerant subjects in whom tolerance was increased by 1 - 7.5 minutes. In four of the vestibular tolerant subjects the changes were quite insignificant, the time increased by 20 - 40 seconds and in one of the subjects from this group a decrease in the tolerance time was noted. From the group of vestibular - tolerant subjects, no change was noted in one of them and in one of them, A-v, who suffered altitude sickness, the vestibular tolerance was lowered significantly.

Analysis of the experimental data indicates that acclimatization in mountains as a rule promotes an increase in tolerance to the vestibular analyzer. This probably is associated with the fact that under conditions of hypoxia the sensitivity of the vestibular analyzer first increases and then gradually decreases.

CONCLUSIONS

1. After adaptation to high-altitude conditions at altitudes of 2000 - 4000 m an increase in altitude tolerance is noted in healthy subjects who had previously not resided at such altitudes. The sharpest high-altitude tolerance increases in subjects who have been actively and sufficiently long acclimatized at altitudes on the order of 3800 - 4200 m.

For the majority of mountain climbers after active acclimati- /65
zation at such altitudes no substantial increase was noted in their altitude tolerance.

2. After adaptation to high-altitude conditions a slight decrease was noted in tolerance to high environmental temperature, whereas the body temperature in the subjects in the heat chamber was increased more rapidly than in the investigations carried out prior

to high-altitude exposure.

3. After exposure at high altitudes, in seven of the 10 subjects, an increase in tolerance to vestibular irritations was noted.

4. In the subject who had suffered altitude sickness after exposure at altitudes of 2000 - 4200 m a decrease in altitude and vestibular tolerance was noted.

REFERENCES

1. Agarkov, F.G: Gigiyena truda i profzabolevaniy, No. 4, p.55, 1959.
2. Vladimirov, G.Ye: In the Book: Kislorodnoye golodaniye letchika i bor'ba s nim. (Oxygen Starvation of a Pilot and the Struggle with It). VMA im. Kirov Press, p. 43, 1939.
3. Malkin, V.B., P.V. Vasil'yev, A.R. Kotovskaya, R.A. Vartbaronov, N.A. Roshchina, G.D. Yukhnovskiy, F.V. Babchinskiy and S.F. Simpura: Materialy konferentsii fiziologov Sredney Azii i Kazakhstana. (Materials from the Conference of Physiologists of Central Asia and Kazakhstan). Dushanbe, p. 224, 1966.
4. Maklin, V.B., N.M. Asyamolova and A.K. Kochitov: Materialy simpoziuma "Gazoobmen v usloviyakh vysokogor'ya". (Materials from the Symposium "Gaseous Metabolism under High-Altitude Conditions"). Frunze, p. 224, 1966.
5. Sirotinin, N.A.: Arkhiv patol. anatomii i patol. fiziol, Vol. 6, No. 1 - 2, p. 35, 1940.
6. Brüner, H, K.E. Klein and D. Jovy: In the Book: Human Problems of Supersonic and Hypersonic Flight. Oxford - London - New York - Paris. Pergamon Press, p. 462, 1962.
7. Hartmann, H., G. Hepp and U. Luft: Luftfahrtmedizin, Vol. 6, No. 1, 1941.
8. Luft, H. In the Book: German Aviation Medicine World. Washington, War II, No. 1, p. 409, 1951.